

II. "Experimental Results relating to the Rhythmical and Excitatory Motions of the Ventricle of the Heart of the Frog, and of the Electrical Phenomena which accompany them."

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The results which are shortly stated in the following paragraphs relate to (1) the order and duration of the rhythmical and excitatory motions of the heart of the frog; (2) the normal electrical condition of the surface of the heart and the influence thereon of mechanical, chemical, and thermal injuries; and (3) the characters of the normal and of the excitatory electrical variation, and the modifications of those characters which are induced by injuries of the surface, and under the temporary influence of radiant heat.

SECTION I.—*Order and Duration of the Motions of the Heart.*

1. *Duration of the Ventricular Systole.*—In the rhythmically contracting excised heart, *i.e.*, in the heart removed by cutting across the sinus, which will in this paper be called "the entire heart," the frequency of the contractions is usually, in winter frogs, a little over 30 per minute. The systole of the ventricle lasts about one second. The contraction attains its maximum in a little more than half a second after its commencement, declining at first gradually, afterwards more suddenly. The sudden relaxation occurs between 0''·7 and 0''·9 after the commencement. At the close of this period the ventricle does not become entirely flaccid, for a lever resting upon it continues to descend for about a third of a second.

In the rhythmically contracting heart, removed by cutting through the auricles, to be called hereafter "the ventricle preparation," the duration of the ventricular systole is about 1''·35. It attains its maximum at 0''·8 after its commencement, and relaxes rapidly between 1''·1 and 1''·3.

In these statements the word commencement is understood to mean the beginning of the hardening of the ventricle. It is preceded by a period of partial contraction of which the duration is about 0''·15, and which we propose to call the period of præ-contraction.

2. *Relation between the Periods of Contraction of the Auricles and Ventricles.*—In the entire heart, contracting rhythmically, the contraction of the auricle begins about 1''·4 before that of the ventricle, and the maximum of the auricular systole is attained 1''·2 before that of the ventricle. There is an interval of not less than half a second between the end of the auricular contraction as indicated by the movement of a light lever resting upon it and the beginning of that of the ventricle. It follows from this statement that when the heart is acting at its normal frequency, the beginning of the auricular contraction nearly

coincides with the maximum of the preceding ventricular systole, and that their endings are synchronous.

3. *The Stannius' Heart*.—In a heart of which the rhythmical action has been arrested by the application of a tight ligature round the line of junction between the wall of the sinus and of the auricles ("Stannius' ligature"), the duration of the ventricular contraction, determined by electrical or mechanical excitation, is much longer than in the beating heart. The contraction attains its maximum from 1''·4 to 1''·8 after the commencement as above defined, the ventricle remaining in full contraction for from 0''·4 to 0''·5. Accordingly the moment at which the sudden relaxation takes place varies between 1''·8 and 2''·0.

4. *Time interval between Excitation and Contraction*.—When a contraction is produced in a heart ligatured as above described (which may be referred to as a "Stannius' heart") by the passage through any part of its substance of a single induction shock, a sensible delay intervenes between the excitation and the commencement of the contraction. If the electrodes are in contact with two points of the surface of the ventricle at a short distance (one millim.) from each other, and currents of small intensity, *i.e.*, such as are just sufficient to produce an effect, are used, the delay may amount to three-tenths of a second. In this case contraction of the auricle commences after that of the ventricle, the time interval between them being from 0''·4 to 0''·5. If the seat of excitation be the posterior surface of the left auricle near the ligature, the auricle contracts after a delay of about one-sixth of a second, but the ventricular contraction does not commence until from 0''·4 to 0''·6 later. It frequently happens that the ventricular systole produced by excitation of the auricle is followed after an interval of inaction of about 1''·3 by a second contraction of the auricles.

SECTION II.—*Electrical Condition of the Surface of the Uninjured and of the Injured Heart.*

5. *The Uninjured Heart*.—It was shown by Engelmann in 1873, that the surface of the uninjured resting heart is isoelectric, and further, that the slightest mechanical or chemical injury renders the injured part negative. These facts we have confirmed in numerous observations relating both to the heart of the toad and of the frog.

Nature of the Injuries Investigated.—In order to investigate the influence of a local injury on the condition of the surface of the heart, its rhythmical motion must be suspended. This may be done either by the passage of a rapid succession of induction shocks in opposite directions through the inhibitory tract, by applying to the surface a trace of a solution of muscarin, or by Stannius' ligature. A localized injury of the surface may be produced either by the scratch of a needle, by touching it with hot wire (preferably a platinum wire heated elec-

trically), by creosote, or by a fine wire covered with a thin layer of fused nitrate of silver.

6. *Comparison of Sound with Uninjured Spots on the Surface of the Resting Heart.*—When the resting heart is connected by its base and apex with a galvanoscopic circuit, and one of the two isoelectrical spots on the surface of the organ by which it is led off is injured in any of the ways above mentioned, the injured spot is found to have become negative to the sound surface. The electrical difference between them may amount to 0.03 volt, but, as Engelmann found, that difference usually diminishes very rapidly.

This effect is for the most part not dependent on the distance of the sound spot from the injured spot. Thus, if an injured spot near the apex is compared (a) with a sound spot 2 millims. from it, and (b) with another near the base, *i.e.*, about 5 millims. distant, it is often found that the differences between the two results are very inconsiderable. This experiment shows that the electromotive forces developed by injury have their seat in the immediate neighbourhood of the injured surfaces.

7. *Influence of Radiant Heat.*—When two isoelectrical points, (*e.g.*, at apex and base) on the surface of the heart are led off, and one of them is warmed by the approach of a platinum coil (about 2 millims. in diameter) heated by a voltaic current and brought into its neighbourhood (3 millims. distant) for a period of one second, the warmed spot becomes *positive* to the other. The amount of difference has not been observed to exceed one-thousandth of a Daniell. No movement of the needle occurs until about a second after the approach of the coil. This effect is transitory, its duration being less than five seconds. If the distance at which the coil is placed is diminished, the warmed surface becomes for a moment positive, then permanently negative. A similar effect is observed when the warming is prolonged without diminishing the distance.

SECTION III.—*Characters and Modifications of the Electrical Variation.*

As was first observed by Köl liker and H. Müller in 1854, an electrical disturbance or variation precedes and accompanies each contraction of the ventricle of the heart of the frog. In the uninjured heart the extent of this variation is extremely small, but is at once increased by injury.

8. *The Normal Variation.*—In the uninjured pulsating heart the variation consists of two phases, *viz.*, of an initial disturbance of short duration, in which the apex becomes positive, and of a much longer second phase, in which the apex tends to negativity. This statement, which relates to the heart cut off through the sinus, is also applicable to the organ while it still forms part of the body. In the entire heart the initial phase begins a quarter of a second before the

commencement of the hardening of the ventricle, *i.e.*, $0''\cdot1$ before the beginning of the præ-contraction. (Sec. I.) The second phase ends about $0''\cdot9$ after the beginning of the first, of which the duration is less than a tenth of a second. Consequently the first phase of the variation is completed $0''\cdot15$ before the commencement of the contraction of the ventricle, its completion being immediately followed by the beginning of the præ-contraction. The second phase lasts through the period of active contraction.

9. *Time Interval between the Excitation and the Variation.*—In the Stannius' heart when the posterior surface of the auricle near the septum is excited, the resulting contraction (as stated in 4) follows the excitation at an interval of about two-thirds of a second. In this case the first phase of the variation precedes the contraction by a very constant interval of a quarter of a second. When the heart is excited from the ventricle half way between the base and apex, left side, the delay is diminished to about a third of a second, but there is no diminution of the interval between the initial phase of the variation and the contraction.

10. *Effect of Injury on the Variation.*—If in a normal entire heart, led off at base and at apex, the surface of the ventricle near the base is injured, the character of the variation is changed, the second phase ("apex-negative") being intensified. If the apex is then similarly injured, the second phase is abolished, the variation being indicated by a single large excursion in the direction of the first phase ("apex-positive").

In the ventrical preparation, the variation, provided that the surface of the organ be uninjured, exhibits two phases, of which the first is identical with the first phase in the entire heart, the second is represented, when investigated with the aid of the capillary electrometer, by a larger excursion in the direction "apex-negative," of which the amplitude is not so great as that of the single excursion observed after injury of the apex. After a time the excursion diminishes in extent and duration, so that, finally, the characters of the normal variation reappear. In a similar manner, if now the surface of the ventricle is injured, similar phenomena to those already described, with reference to the entire heart, present themselves, according to the seat of the injury. If it is at the apex, whether it be mechanical or chemical, the whole variation is represented by a single large excursion (apex-positive); if it is at the base there is a præ-excursion, in which the apex becomes momentarily positive, followed by a more prolonged excursion in the opposite direction, corresponding in direction to the second phase.

It has been already shown, in 6, that the electrical difference between a sound and an injured surface is not materially affected by distance. In like manner, the excursions which present themselves

when two spots, 2 millims. apart, of which one has been injured, are led off, nearly equal in amplitude those which are observed when the contacts are respectively at apex and base.

11. *Decline of Effect after Injury*.—The electrical difference between an injured and a sound surface begins to decline from the moment of the infliction of the injury which produces it. This decline is not accompanied by a corresponding diminution of the variation, the eventual decline of which is often preceded by a temporary increase.

12. *Modifications observed under the Influence of Radiant Heat*.—By warming the surface of the ventricle in the manner described in 7, the following changes are produced in the character of the variation. In the uninjured rhythmically contracting heart, in which the variation has the normal character, the approach of the wire for five seconds to a distance of 3 millims. from the surface of the auriculo-ventricular groove intensifies the second phase and increases its duration. This effect lasts for two minutes at most. It subsides at first rapidly—so that each succeeding variation differs sensibly from the preceding one—afterwards more gradually.

If the apex be similarly warmed, the second phase is either obliterated or reversed, according to the time of exposure and to the distance of the coil. At first the variation assumes the characters witnessed after injury of the apex, as described in 10; but here, as when the base of the ventricle is warmed, the effects subside rapidly during the first five seconds, more gradually afterwards. In both cases the variation has, in about two minutes, resumed its normal characters.

In the above experiments it is seen that, although the warming influences the potential of the surface acted on in a direction which is opposite to that produced by a permanent injury, its effect on the variation is precisely the same, with this important difference, that it is transitory. These effects can be observed whether the entire heart or the ventricle alone is used.

13. *Modifications dependent on the Seat of Excitation*.—If in the entire heart, of which the motions have been arrested, either by faradization of the inhibitory tract or by the Stannius' ligature, a single contraction is induced either by a mechanical or electrical excitation of any part of the auricles or of the auriculo-ventricular groove, the excursions present the same characters as in the rhythmically contracting heart. If the excitation, whether electrical or mechanical, be at the apex, the first phase of the variation is *reversed*, i.e., the apex becomes initially *negative*. In other respects the excursion is unaltered. Consequently, if at the moment of excitation the apex is warmed in the manner previously described in 12, the large single excursion (apex-positive) is seen to be preceded by a momentary præ-excursion in the opposite direction.